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Effect of Different Welding Parameters on the Mechanical and Microstructural Properties of Stainless Steel 304H Welded Joints

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ABSTRACT

In this research work, an attempt has been made to examine the different welding parameters which affect the weldability of 304H Austenitic stainless steel (ASS) welded joint using the proper filler wire. Chemical composition of filler wire was same as that of base metal. Further this study addressed the combined effect of various welding parameters on the metallurgical and mechanical properties of the weldments. Welding was carried out at different parameters such as welding wire speed, shielding gas flow rate, welding current and arc voltage etc. Tensile tests and V-notch Charpy tests were conducted as per ASTM to determine the mechanical properties of the welded specimens. In order to determine the microstructured changes that occurred, the interface regions of the welded specimens were examined by microscope. As a result, it is reported that changing the shielding gas flow rate and wire feed speed affects the microstructure and mechanical properties of weldment. Impact tests reveal that toughness of the welded joint increases with increasing in welding current, while ultimate tensile strength (UTS) first increases and then decreases.

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1. INTRODUCTION

Nowadays welding is widely used in all types of industries and usually it is defined as a branch of engineering and technology that is used to join the same/different materials [1] under different conditions. In this research work, Gas Metal Arc Welding (GMAW) is used to bond the Stainless Steel 304H. GMA welding is a joining process in which a continuous copper coated wire is used. MIG welding is chosen due to its numerous advantages over conventional welding [2]. Stainless Steel 304H material is extensively used in chemical, petrochemical, biomedicine and nuclear reactors industries due to its high tensile strength, good corrosion resistance and excellent ductility [3, 4]. Shielding gas flow rate is one of the welding parameter which also affects the properties of welded joint, more over it also determines the shape and penetration pattern in welding process [5, 6]. During welding process shielding is very helpful to produce good strength, toughness and corrosion resistance welded joint [7].

In welding process shielding gas protects molten metal pool from any atmospheric contamination and also stabilizes the arc and promotes uniform metal transfer [8].

Weldability of any material is referred as a capability by which it can be easily welded. Weldability of any material may be considered as: (i) suitability of the material which allows elements to be combined (the so-called metallurgical suitability), (ii) the process of selecting the method, energy source of heat, speed of welding, etc. (the so-called technological or operational suitability), and (iii) the result of welding, evaluation of the resulting weld, load distribution of the element, and its stiffness (the so-called constructional suitability) [9]. The basic aim of this research article is to determine the effect of various welding parameters on the mechanical and microstructural properties of Stainless Steel 304H welded by GMA welding process. Choudhary and Duhan [10] studied the effect of activating flux (MnO_2, ZnO, Fe_2O_3 and $MgCl_2$) on mechanical properties of

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SS304 and they observed an improvement in the mechanical properties. Weld morphology also improves using different types of activated flux in comparison to the ordinary TIG welding. Doniavi et al. [11] applied RSM and ANOVA for prediction and optimization of mechanical properties of St52 in GMAW. They observed that the temperature difference between the weld HAZ areas results in lower tensile stress. Zarouni and Eslami-Farsani [12] determined the effect of heat input on the intermetallic compound layer and mechanical properties in arc welding-brazing dissimilar joining of aluminum alloy to galvanized steel. They observed that increasing the weld heat input enhanced the thickness of IMCs layer formed at the interface of steel/weld seam. Sathiya et al. [13] investigated the effect of shielding gases on the weld bead and mechanical properties of AISI 904L bonded by CO_2 laser-GMAW hybrid welding. They concluded that joining laser-GMAW hybrid had higher impact and tensile strength. Palani and Murugan [14] studied the effect of wire feed speed and pulsed current during the welding of 317L by flux cored wire. Authors concluded that wire feed speed is affected by the changes in welding current. Kumar et al. [15] studied the microstructure and mechanical properties of 304 austenitic steel welded by GTA and SMAW. Impact testing revealed that welds made using SMA exhibited significantly higher toughness as compared to TIG welding as the filler does not contain boron.

2. EXPERIMENTAL PROCESS

In this research work austenitic Stainless Steel 304H was selected as work piece with dimensions of 150× 50×5 mm. Chemical composition of base metal and filler wire are shown in Table 1. GMA bead-on Stainless Steel 304H plate weld for microstructure examination and butt welding for tensile test were carried out by a semiautomatic welding machine (Lincoln USA make) with a filler wire of ER308 grade.

To determine the weldability of Stainless Steel 304H, welding was carried out at various welding parameters and these parameters are listed in Table 2.

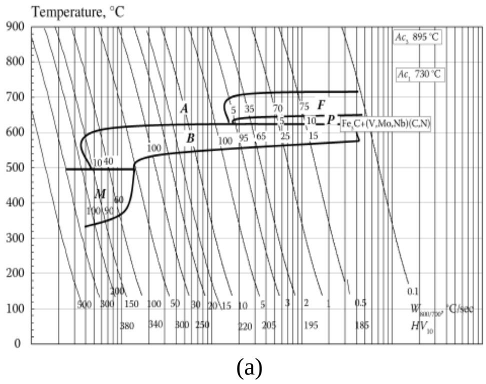
In welding, HAZ is defined as heat affected zone and it is a zone of base material, either a metal or a thermoplastic, which is not melted and has its microstructure and properties changed by welding. Formation of austenite transformation in Stainless Steel 304H in HAZ is shown in Figure 1.

TABLE 1. Chemical composition of parent metal and filler wire

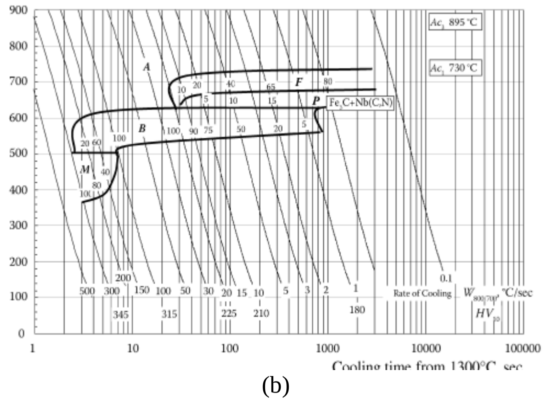
Material	C (%)	Cr (%)	Ni (%)	Si (%)	Mn (%)	p (%)	S (%)	Fe
Stainless Steel 304H	0.08	18.20	8.5	0.45	1.55	0.012	0.03	rest
Filler wire ER 308	0.05	18.5	10	0.4	1.7	0.05	0.032	rest

TABLE 2. Welding process parameters

Factors I	Unit	Level I	Level II	Level III
Welding current	A	150	150	150
Arc voltage	V	20	21	22
Shielding gas flow rate	l/min	10	15	20
Wire feed speed	IPM	250	300	350



(a)



(b)

Figure 1. Austenite transformation in HAZ in steel of composition No. 1 (*a*) and composition No. 2 (*b*) [5]

Ferrite forms in the temperature range of 740–630°C, starting with a cooling rate of 20 °C/sec (see Figure 1(b)). Martensitic transformation occurs in the range 500–360 °C and the critical cooling rate for incomplete quenching is in the range 90–280 °C/sec.

In this research work pure Argon was used as shielding gas. Shielding gas range was from 10 to 20 l/min. Welding was carried out by 2 mm diameter wire. For microstructure examination, welded parts were cut transversely from joint.

For mechanical test purpose different tests, for example, ultimate tensile strength (UTS), toughness, microhardness were completed. Microhardness was assessed on hardness analyzer under a heap of 10 kg for 10 s. Tensile test specimen are shown in Figure 2 which were prepared as per ASTM. Microstracture of welded specimens were dissected at (Devender make), magnifying instrument. micrcamsoftware. Micrstructure tests arranged for microstructure as appeared in Figure 3. Figure 2 shows the failure of tensile test specimens at weld bead portion.

After cold setting test pieces were ground on a double disk polishing machine with various evaluations of emery paper I,e from 80 to 1500 micron for 10 min each, at the speed scope of 250-350 rpm. In the last test, pieces were cleaned by Alumina suspension glue. After that etched specimens were carved in Glyceria arrangement and swab up to 2 min through experimentation technique. Etching was performed at room temperature. Test pieces were then ready for microstructure examinations.

Figure 2. Samples for ultimate tensile strength as per ASTM [17]

Figure 3. Samples for microstructure examination

3. RESULTS

3.1. Microstructure

The experimental results after MIG welding were estimated in terms of the following measured performances: (1) ultimate tensile strength (UTS), (2) microhardness and (3) impact energy (IE) of charpy impact test results of welded specimen before fracture. In order to attain supreme weldability, nine experiments were conducted.

Figure 4(a)-(i) show the microstructure behavior of Stainless Steel 304H welded joint sample with Ar as a shielding gas. These samples were welded at given values of welding parameters such as voltage and flow rate of shielding gas and wire feed speed. In microstructure of welded sample, cooling rate and heat input play an important role to affect the microstructure [8]. Figure 4 shows microstructure of weld pool at different heat input.

From Figure 4 it is very clear that solidification microstructure of welded pool differ from cellular to dendritic microstructure from fusion line and format of delta- ferrite is different in austenite region.

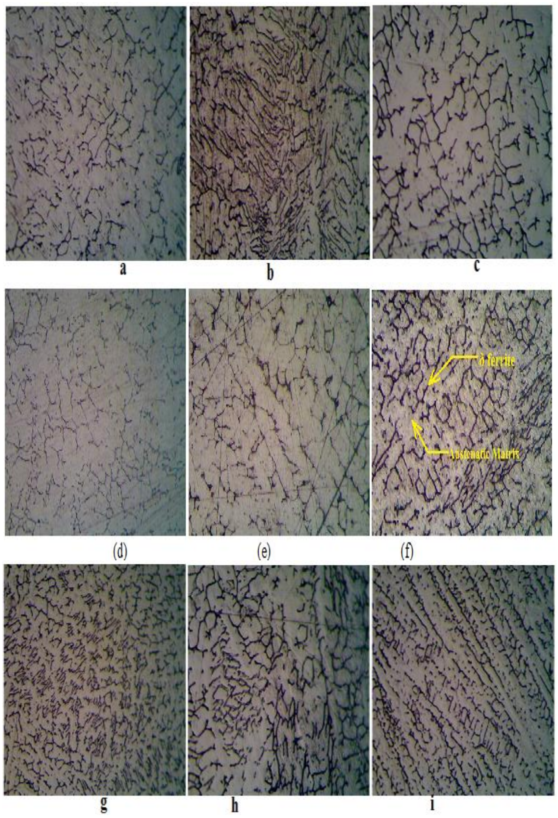


Figure 4. Morphology of delta ferrite in samples (a) continuous network no.1, (b) continuous network no.2, (c) semi continuous no.3, (d) isolated no.4 (e), continuous network no.5, (f) continuous network no.6, (g) continuous network no.7, (h) continuous network no.8 and (i) continuous network no.9

It is only due to the different welding conditions as mentioned above and it is also very clear from the results that grain size of welded joint increases with increasing current. The results of this work are consistent with the report of Gulenc et al. [16].

The formation of delta-ferrite promotes the formation of chromium depleted zone which harms the austenitic behavior.

3. 2. Mechanical Properties For mechanical examination tensile test, impact charpy test and microhardness test was carried out for different samples. To determine the UTS of welded samples, specimens were tested on universal testing machine and after test, failure occurred at weld bead portion.

3. 3. Microhardness of Welded Joint Microhardness of weldment was measured from transverse direction. Figure 5 shows the hardness profile of welded joint. It also indicates that at the top of the weld bead hardness value is higher. It is only possible due to faster cooling rate at the top of weld bead portion [17]. From Figure 5 it is observed that for low heat input microhardness of weldment increases from 199 VHN, 186 for medium and 160 VHN for high heat input. Results of microhardness of this research are in agreement with the others [18].

3. 4. Toughness of Weldment Toughness is of great importance for high strength steels when they are used at low temperature conditions. Impact test of weldment was carried out at room temperature. Impact V notch specimens is shown in Figure 6. Test piece are fabricated as per ASTM [19] standard. V notch was cut at center of test pieces as shown in Figure 6.

TABLE 3. Values of UTS, microhardness and impact strength

S.No	Voltage (V)	Wire feed speed (RPM)	Gas flow rate (l/h)	Current (Amp)	UTS (MPa)	Microhardness	Impact strength (J)
1	20	250	10	150	470	182	178
2	20	300	15	150	510	161	160
3	20	350	20	150	505	181	240
4	21	250	10	150	437	190	246
5	21	300	15	150	528	165	198
6	21	350	20	150	497	175	266
7	22	250	10	150	480	190	250
8	22	300	15	150	453	199	262
9	22	350	20	150	525	177	240

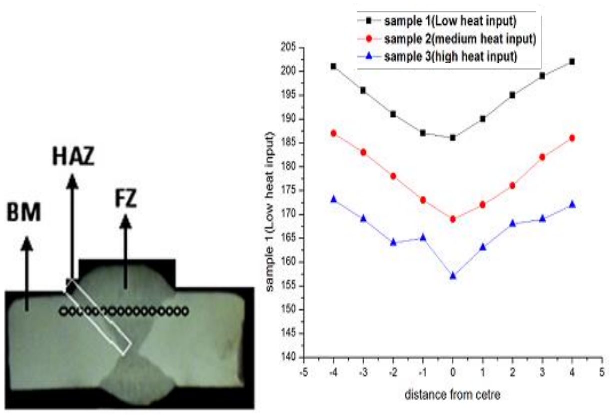
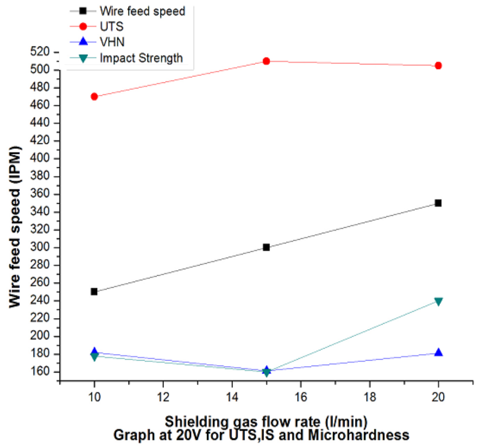


Figure 5. Microhardness at different zone of welded joint at various heat input

Effect of wire feed speed and shielding gas flow rate on ultimate tensile strength, toughness and microhardness of weldment is presented in line format as well as bar format at different volts in Figure 8 (a)-(f).

Figure 6. Position of notch in toughness sample as per ASTM [19]

It is observed in this figure that format of line diagram and bar chart is not symmetrical. The figure also shows a comparison of mechanical properties of weldments at different voltages. From Figure 8 (a)-(f) it is very clear that toughness of welded metal first decreases and then increases. Figure 9 shows toughness test piece after fracture. It is very clear that V notch test piece were failure at V notch center line.



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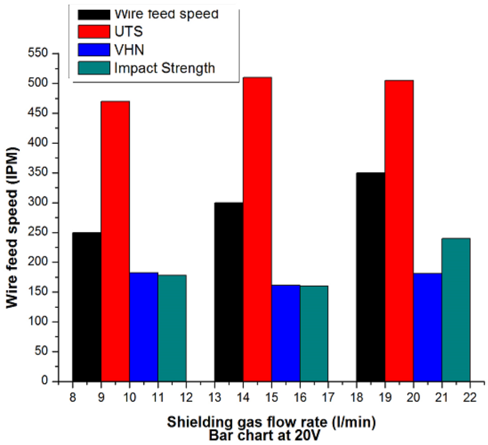

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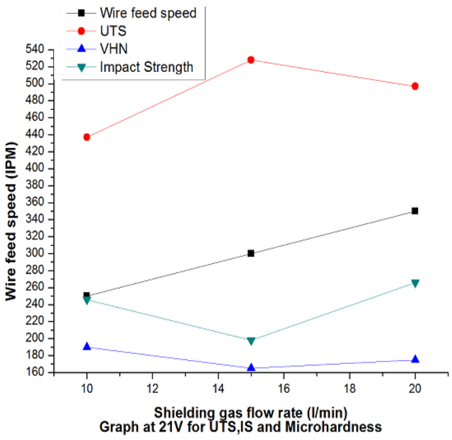

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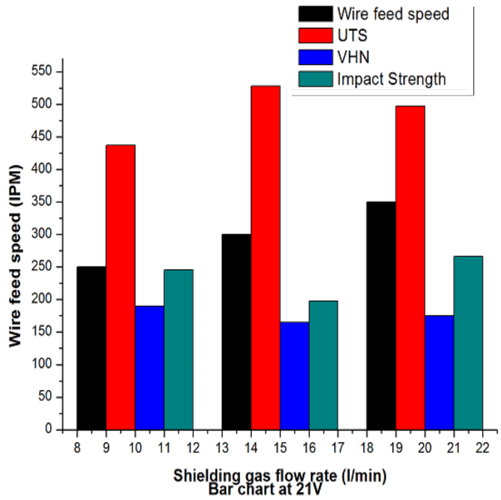

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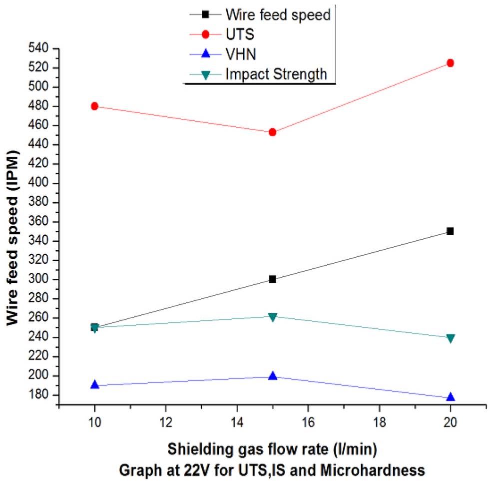

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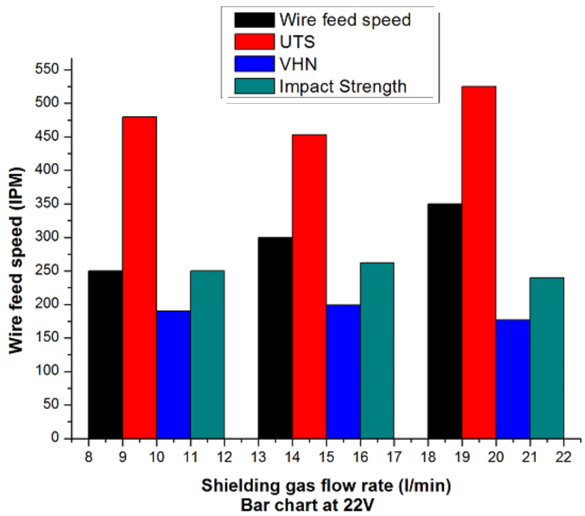

(f)

Figure 8. (a-f) Effect of wire feed speed and gas flow rate on UTS, toughness and microhardness of welded joint

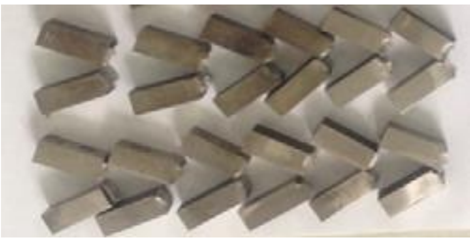

Figure 8. Toughness test pieces are fractured

4. CONCLUSSION

In this research article Stainless Steel 304H with 6 mm thickness V-groove welded with MIG welding process; the following conclusion are derived from the experiments:

1. Highest tensile strength was obtained at 21V
2. Impact strength of welded samples were also found highest at 21V
3. Microstructure of welded samples showed not any cracking, tearing or any related defects
4. Grain size of Stainless Steel 304H welded joints were different at different gas flow rates and wire feed speeds.
5. Grain size of welded joint increased with increasing the heat input.
6. In Figure 4(a)-(i), some grains are fine and some are coarse. It is only due to effect of various welding parameters.
7. Full penetration was achieved in welded joint without any defects
8. UTS, hardness and toughness of welded joints are functions of microstructure hence all these properties are structural penetrating.
9. There is sudden decrement in microhardness values from low heat input to higher heat input.
10. It is observed from microhardness measurements that hardness near the upper surface of the weldment is highest and lowest near the center of the weld, only due to the cooling of the outside rather than inside of the weldment portion.

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چکیده

در این تحقیق تلاش شده است که پارامترهای جوش مختلفی که بر جوشکاری فولاد ضدزنگ آستنیتی (ASS) ۳۰۴H جوش داده شده با استفاده از سیم پرکن تاثیر گذارند، مورد بررسی قرار گیرند. ترکیب شیمیایی سیم پرکننده همانند فلز پایه بود. علاوه بر این، این مطالعه به ترکیب اثر پارامترهای مختلف جوش بر خواص متالورژیکی و مکانیکی نقاط جوش داده شده اشاره دارد. جوشکاری با پارامترهای مختلف مانند سرعت سیم جوش، سرعت جریان گاز محافظ، جریان جوش و ولتاژ قوس و غیره انجام شده است. آزمونهای کششی و آزمایشات V-notch Charpy بر اساس ASTM برای تعیین خواص مکانیکی نمونه های جوش انجام شده است. به منظور تعیین تغییرات ریز ساختاری که رخ داد، مناطق خطوط رابط نمونه های جوش داده شده با استفاده از میکروسکوپ مورد بررسی قرار گرفتند. در نتیجه، گزارش شده است که تغییر جریان گاز محافظ و سرعت انتقال سیم بر ریزساختار و خواص مکانیکی جوش تاثیرگذار است. آزمون های ضربه نشان می دهد که چقرمگی نقاط جوش داده شده با افزایش جریان جوش افزایش می یابد، در حالی که UTS ابتدا افزایش و سپس کاهش می یابد.

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